Lab 4: Friction

Description

In this lab, you will explore the difference between static and kinetic friction. You will also explore possible factors that may affect the force of friction.

Equipment

- Inclined Plane
- Masses (50 and 100 gram increments)
- Mass Hanger
- Pulley
- String

Introduction

A contact force is any force that is transmitted by the physical contact of two bodies. Contact forces include pushes or pulls exerted with your hand, the force of a rope pulling a body to which it is tied, and the friction force between an object and the surface upon which it rests or slides. It is the force of friction we will be concerned with in this experiment.

Friction is the resisting force which opposes the motion or attempted motion of one body over another. The force needed to overcome friction depends on the nature of the materials in contact, and varies from one material to another. For example, the friction force between two smooth surfaces in contact, such as marble or tile, is less than the friction force between two rough surfaces in contact, such as tires on pavement.

To illustrate this, imagine pushing a box across the floor. If the magnitude of the force, $F$, that you exert on the box is small, the frictional force, $f$, acting in the direction opposing $F$, will keep the box from moving, and the box remains in a state of static equilibrium. If the magnitude of the force, $F$, is gradually increased, the box will begin to move across the floor. Once the box begins to move, however, it requires some force $F$ to keep it moving at a constant velocity across the floor. Because the box is moving at a constant velocity, it is in dynamic equilibrium. Thus, the force of friction between the box and the floor must be equal in magnitude and opposite in direction to $F$.

In the case in which the box remains in static equilibrium (unmoving), the frictional force which opposes $F$ is called the force of static friction, $f_s$. Similarly, in the case in which the box is in either dynamic equilibrium (constant velocity) or experiencing some kind of acceleration, the frictional force which opposes the motion is called the force of kinetic friction, $f_k$. Both $f_s$ and $f_k$, are related to the perpendicular contact force between the box and the surface by the relationship:

$$f_{s,k} = \mu_{s,k}N$$

where $N$ is the magnitude of the normal force between the box and the surface, and $\mu_{s,k}$ (Greek lower case mu) is the coefficient of static ($\mu_s$) or kinetic ($\mu_k$) friction between the box and the
surface. The coefficient of friction again depends on the nature of the materials in contact, and varies from material to material. The coefficients of friction are determined experimentally, and are listed in tables by material. Also, the values of $\mu_s$ and $\mu_k$ are always less than 1. In this experiment, you will be determining the coefficients of both static and kinetic friction for a wood block on an inclined plane.

In general, $\mu_s$ is larger than $\mu_k$. To understand this, consider the example of pushing a car that is in neutral. It takes more force to start the car moving than it does to keep it moving once it is already moving. Thus, the force of static friction is greater than the force of kinetic friction between the tires and the road, and the coefficient of static friction is greater than the coefficient of kinetic friction.

A note about Equation 1: as you can see from Figure 1, the force of friction between the surface and the box is parallel to the surface, while the normal force is perpendicular to the surface. Equation 1 is to be used only with the magnitudes of these forces, not their directions, as two vectors can only be related by a constant if they are in the same direction.

Before doing so, though, let us solve Equation 1 for $\mu$ by dividing both sides by the normal force.

\[
\mu_s = \frac{f_s}{N}, \quad (2)
\]

\[
\mu_k = \frac{f_k}{N}, \quad (3)
\]

Both equations look like the slope of a line of a graph where $f_s$ or $f_k$ is plotted on the vertical axis, and $N$ is plotted on the horizontal axis. If a line of best fit is plotted through the data points, you should see a linear relationship between the force of friction, $f_s$ or $f_k$, between the block and the inclined plane, and the normal force on the block, $N$. Recall that the slope of a line is calculated by \( \frac{\text{rise}}{\text{run}} \) or \( \Delta y / \Delta x \), where $\Delta$, the Greek upper case letter Delta, means change in. In Equations 2 and 3, then, $f_s$ or $f_k$ correspond to $\Delta y$, or the rise, on the vertical axis, and $N$ corresponds to $\Delta x$, or the run, on the horizontal axis of the line. From Equation 2 and 3, then, the slopes of these lines are equal to the coefficients of friction between the block and the inclined plane, the values which you will determine in this experiment.

**Procedure**

The setup used in this experiment is depicted in Figure 1, and consists of a mass on an inclined plane of adjustable angle. The mass is tied to a string which is run over a pulley, which is assumed to be massless, and then tied at its other end to masses on a mass hanger. In this case, because there is no motion in the vertical direction, the normal force is equal to the weight of the block and any additional mass placed on top of it. Also, (see Appendix C for further explanation), the magnitude of the friction force acting between the block and the surface is equal to the weight of the mass and the mass hangers at the end of the string over the pulley:

\[
W_2 = f_{s,k} \quad (4)
\]

**Coefficient of Kinetic Friction**

1. Create a table in your lab book for the coefficient of kinetic friction measurements and calculations. The table should have the column headings: Trial Number, Mass of the Block [kg],
Mass Placed on the Block [kg], Total Mass [kg], Total Weight of the Block and Masses [N], Total Normal Force $F_N$ [N], Total Mass at the end of the String [kg], Total Weight at the end of the string [N], Force Needed to Move the Block Uniformly (Force of Kinetic Friction) $f_k$ [N]. Make sure you leave enough space in each column to record both the measurement and the error. You will have 6 total trials when the table is complete.
2. Use a triple beam balance to find the mass of the wood block, and record it in your data table. Calculate the weight of the block and record it in your data table.

3. Keeping the board horizontal, place the block on top of the board, connect the string to it, and run the string over the pulley.

4. Measure and record the mass of the hanger above your data table. Add small masses to the hanger until the force created is just enough to keep the block moving with a constant speed when it has been started with a gentle push.

   **Note:** because the surface upon which the block is sliding is uneven, the motion of the block may not be exactly uniform. In other words, the block may appear to slow down and speed up as it travels over the rough surface of the board. This is okay because all we are looking for is an overall constant motion, or an average.

5. Record the final mass and its weight in your data table.

6. Repeat step 2 through 5 for five more trials, adding an additional 50 [g] on top of the block each time.

7. Using the data from the columns 'Total Normal Force' and 'Force of Kinetic Friction', make a graph with 'Force of Kinetic Friction' on the vertical axis and 'Total Normal Force' on the horizontal axis.

8. Draw a line of best fit through your data points. Choose two points on your line of best fit and use them to calculate the slope of the line from Equation 2 and 3 to obtain the coefficient of kinetic friction.

   **Note:** A complete graph will have: a descriptive title, both axis labeled (with units), data points with error bars (in different colors if there is more than one set of data), a fit line with the equation of the line printed on the graph, and a legend that tells the reader what the data is.

**Coefficient of Static Friction**

1. Create another table with the same titles as the first one but replacing the 'Force Needed to Move the Block Uniformly' with 'Force Needed to Start Moving the Block (Force of Static Friction) $f_s$'

2. Repeat steps 2 through 8 in Part I, but this time, do not give the block an initial push. Instead, add masses to the hanger until the block moves with uniform velocity. If the block accelerates, start the trial over, using slightly less mass on the hanger. Also, you will find the coefficient of static friction from the slope of your graph.

**Coefficient of Static Friction on an Incline**

In this part of the experiment, we will consider what happens when we have a situation like that depicted in Figure 5 in the attached Appendix. In this case, the normal force and the weight
Figure 3: Laboratory setup for part III.

of the block are no longer equal. Instead, the normal force is equal to some fraction of the weight of the block:

\[ N = W \cos \theta \quad (5) \]

where \( \theta \) is the angle at which the plane is inclined. Now, the coefficient of static friction is given by:

\[ \mu_s = \tan \theta \quad (6) \]

1. Create a third table with column headings: Trial Number, Angle \( \theta \), and Coefficient of Static Friction \( \mu_s \). You will have 5 trials recorded in this table.

2. Remove the string and attached mass hanger from the block and begin with the board horizontal. Place the block near the end of the incline closest to the pulley.

3. Slowly raise the end of the plane until the block starts to move. Record the angle in your data table, and repeat this another four times, for a total of five trials.

4. Use Equation 6 to calculate the coefficient of static friction, \( \mu_s \). Take the average of all five values, and compare this value to that obtained in Part II by calculating the percent difference between the two values.
Analysis

1. Why does the block need to be moving with a constant velocity when measuring the kinetic coefficient of friction?

2. How does your value of $\mu_s$ compare to your value of $\mu_k$? Is this the result that you should see? Why?

3. In step 4 in the Procedure of Part III, what should the value of $\mu_s$ be and how does this compare to the value you found in Part II of this lab? What might be some sources of any discrepancies between these two values?
Appendix C: A Detailed Description of Friction

Consider the setup used in Parts I and II of this experiment, with all forces drawn and labeled:

![Figure 1: Part I and II experiment setup with forces labeled.]

When performing this experiment, we take the system to be in dynamic equilibrium, i.e., all bodies in the system are moving at constant velocity. (If the system is not in equilibrium, what does that mean about the following math?) Thus, we can easily apply Newton’s Second Law to both bodies in the system. If we begin with \( m_2 \), the only forces are in the vertical direction, and because the block is not accelerating, we have:

\[
\vec{T} + \vec{W}_2 = 0 \quad (1)
\]

or

\[
T - W_2 = 0 \quad (2)
\]

which means,

\[
T = W_2 \quad (3)
\]

If we do the same for \( m_1 \), considering forces in the horizontal direction, we have:

\[
\vec{T} + \vec{F}_f = 0 \quad (4)
\]

or

\[
T - F_f = 0 \quad (5)
\]

which means,

\[
T = F_f \quad (6)
\]

Because there is only one rope, the tension in the rope is equal at all points in the rope, and thus, equating Equations 3 and 6, we get Equation 4 from Lab 4: Friction.
For Part III, consider Figure 2 where the plane upon which the block rests is now inclined. For simplicity’s sake, we have defined our axes to lie parallel and perpendicular to the plane. In doing so, we have broken up the block’s weight vector into components parallel and perpendicular to the plane. If we apply Newton’s Second Law in the direction parallel to the plane, we get:

\[ \vec{F}_f + \vec{W}_\parallel = ma \]  \hspace{1cm} (7)

or

\[ F_f - W \sin \theta = ma \]  \hspace{1cm} (8)

If \( a=0 \),

\[ F_f = W \sin \theta \]  \hspace{1cm} (9)

Replacing \( F_f \) with \( \mu N \):

\[ \mu N = W \sin \theta \]  \hspace{1cm} (10)

Now considering Newton’s Second Law in the direction perpendicular to the plane, we get:

\[ \vec{N} + \vec{W}_\theta = ma \]  \hspace{1cm} (11)

or

\[ N - W \cos \theta = ma \]  \hspace{1cm} (12)

If \( a=0 \)

\[ N = W \cos \theta \]  \hspace{1cm} (13)

Finally, if we divide Equation 10 by 13, \( N \) and \( W \) cancel, and we obtain Equation 6. In Part III, you are only attempting to determine \( \mu_s \), but recall that \( \mu_s < \mu_k \). Thus, for Equation 6 from Lab 4, \( \theta_s > \theta_k \).